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ABSTRACT

An instructional system that is both efficient and effective should present information so that it is easily processed by learners and so that the cognitive structures resulting from instruction correspond to the structure of the content to be learned. This paper presents a discussion of methods for describing content structure and cognitive structure and for comparing the two. Research methods for studying changes in cognitive structure as a result of instruction are presented and illustrated by a number of studies. Finally, implications of structural approaches to cognition and content are examined for the design of instructional systems. (Author)

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CONTENT STRUCTURE AND COGNITION IN INSTRUCTIONAL SYSTEMS

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There is an increasingly prevalent belief among psychologists and educators that limiting the study of learning and cognition to obversable facets of human behavior provides a distorted picture of both the learner and of learning processes. An emphasis on the study of behavior has necessarily limited our examination of the way in which humans process information, store, and manipulate it in memory. An emphasis on overt behavior limits the study of learning to learning outcomes, not the cognitive activity that underlies them, and, in education, limits teaching to what can be tested and measured. (Mitchell, 1972; Winn, 1975, 1977). That this is unsatisfactory becomes obvious in the light of recent interest in the processes of learning, the study of imagery, and cognitive structuring.

The activities of "cognitive", as opposed to "behavioral" psychologists are extremely varied, and for this reason alone, it is difficult to provide a brief description of what the recent developments in the study of learning processes and structure are all about. However, it is probably safe to identify a few general postulates that underlie most of what cognitive psychologists maintain:

i. People understand the world about them by means of some form of inner representation of it. These representations are generally called cognitive structures.

ii. Learning takes place when cognitive structure change. This change can be brought about either by the perception and processing of some new information in the environment, which is then assimilated to existing cognitive structures, in turn altering them (Piaget, 1967), or by internal reorganization brought about by maturation (Piaget, 1950), insight, or some inner creative impulse.

iii. Cognitive structures can be described empirically in a variety of different ways (Scott, 1966, 1969).

iv. Often cognitive structures can best be described as networks of interrelated concepts forming a coherent conceptual domain.

v. Even within clearly defined conceptual domains, there is great variability between the cognitive structures of different individuals.

Closely related to this last point is the matter of cognitive style and aptitude. Differences in cognitive style determine which learners will tend to favor which information presented to them in different ways, and how they will each process that information. Aptitude has to do with the actual ability (rather than the preference) of the learner to perceive and process information in different ways. Both of these topics will be dealt with in more detail later.

By first postulating and then studying cognitive structures, the cognitive psychologist is greatly expanding the area that he has to deal with. Not only are overt learner behaviors still fair game to be studied, for the outcome of some changes in cognitive structure will always be overt actions. But now even those changes that are not directly observable enter into the picture as well. Moreover, to understand how learning takes place through the change of structures, the processes of the assimilation of new information and the accomodation of existing structures to it must also be studied. Finally, structural approaches to learning throw into very sharp relief the problem of individual differences between learners. The formation and modification of cognitive structures are affected by such things as aptitude and cognitive style to such an extent that it is no longer satisfactory to suppose that one set of learning activities and resources is adequate for the instruction of a group of learners. Admittedly, individualization of instruction has been with us in various forms for many years. The study of cognitive processes and structures serves to emphasize its importance. Going even further, it is legitimate to question seriously the traditional assumption of education that everyone should come out of an instructional activity knowing the same things and with identical behaviors. It appears that this particular aim of instruction should be limited to those areas where it is absolutely essential, for example motor skills, perceptual recognition and political indoctrination (should it ever be justifiable).

With great variability in learners, learning processes and learning outcomes, it becomes necessary to provide learners with a great variety of instructional options. With variety comes complexity, and the need for systematic management of the learning process. An instructional system is a complex whole of many parts, offering the learner many alternative pathways to follow both in the objectives of instruction and in the ways in which those

objectives are achieved. It is only through systems approaches to education, the systematic analysis and solution of instructional needs and problems, and the systematic application of those educational technologies that permit effective and efficient instruction to take place, that the needs of the learner, identified by study of cognitive structures and information processing, can be met. Structural orientations to learning and cognition of necessity go hand in hand with systems approaches to instruction.

What then should an instructional system aim to do? In a narrow sense, it should provide each learner with the best way of allowing cognitive structures to be built that correspond as closely as possible with some external structural criterion. This immediately poses a serious question. Doesn't this bring us right back to where we started from: where instruction is seen as the process whereby learners are herded towards an objective determined by a teacher or curriculum guide? The answer to this is, of course, that it is in the manner of the herding that a fundamental difference lies. The learner can get there anyway he likes, and when he gets there it is the way in which his ideas are organized that is questioned, not his ability to "give back" the information he has received. In a broader sense, however, this approach does allow the learner freedom to construct his perception of the world in any way he wants. Obviously, this is not always a good thing. There are many occasions when accurate and objective understanding is required, and when the correct performance of skills is essential. However, there are other occasions when the similarity of a learner's cognitive structure to some externally imposed criterion is either irrelevant, or at least not the basis for making a value judgment. It is in this area, where for example student opinions are respected, and student interpretations of information are given equal value to teachers' interpretations that the study of changes in cognitive structurs is of great value. There is something attractive about a teacher being able to say at the end of instruction, that, for a certain student, "this is" rather than "this is right". Description replaces evaluation.

In what follows, ways of applying cognitive and information processing theory to the design of instructional systems are examined. In doing this, the basic form of the development process is retained. For example, task analysis and learner analysis still occur. The differences reside rather in what happens at each step in the process. Within the structural rather than

the behavioral development paradigm, task analysis becomes something very different from the more usual method of preparing a checklist of enabling behaviors. Learner analysis too must take account of cognitive style and aptitude and must, in more general terms, treat the learners themselves as complex systems of many variables. The production of materials and the implementation of the system once it has been designed and tested are virtually unchanged. For this reason, most of the following will be devoted to a look at task and learner analysis.

Task analysis

Since cognitive approaches to learning are concerned with the way in which learners arrange concepts within cognitive structures in memory, and since the intention of instruction is to convey to learners not just the nature of individual concepts but also the way in which they are logically interrelated, it is necessary for the designer of instructional systems to know the structural relationships between the concepts that form the content that is to be learned. This is accomplished through task analysis . But for task analysis to succeed in defining the structure of a particular conceptual domain, our idea of what task analysis is must be changed in two ways. The term "task analysis" must now apply to cognitive structures and not just to observable "tasks"; it must also imply an analysis of the processes as well as the outcomes of learning. In both of these areas, it can either be carried out rationally or empirically, using either reliable and objective techniques of the structure of conceptual domains or data on how people do in fact structure them. The possibilities that these considerations open up for task analysis are summarized in figure 1.

Traditionally, task analysis has been concerned with identifying observable behaviors that the learner must perform in order to be able to attain a particular objective. In this way, it has been restricted to the outcomes of learning rather than learning processes, and to learner performances rather than the cognitive structures that underlie them. (For the sake of clarity, both cognitive structures and learner tasks are considered to be outcomes of learning. It is also assumed that there are learning processes associated with the formation of cognitive structures and the performance of tasks.) That the traditional approach to task analysis ultimately restricts instruction to

observable behavior has been argued before. There is a lot that happens in learning that is not directly observable, and there is a lot of cognitive activity that precedes a learning outcome. The instructional designer needs to understand both of these. Cognitive psychologists have argued for the importance of understanding learning processes and cognitive structures in order to understand fully why a learner behaves as he does. Task analysis should therefore tie "tasks" to both learning processes and cognitive structures. A discussion of the various possibilities suggested in figure 1. will reveal several attempts to apply the methods of cognitive psychology to the description of tasks and learning processes, and will also indicate places where such attempts still need to be made.

	Rational		Empirical	
	Structure	Task	Structure	Task
Process	1. Computer Simulation Using semantic networks. (LNR group)	2. Information-processing analysis. (Resnick)	5. Experimental study of assimilation, accomodation and equilibrium (Piaget)	6. Experimental study of information-processing
Outcome	3. Semantic networks, digraph analysis of prose. (LNR group, Shavelson)	4. Traditional, subject-matter "experts"	7. Word-association, relatedness coefficients, factor analysis, multi-dimensional scaling. Tree-construction (Deese, Shavelson, Preece)	8. Traditional, testing informed subjects

Figure 1. An expansion of task analysis.

It is perhaps appropriate to begin our examination of task analysis options at the place where we are most at home. These are cells four and eight in figure 1., where the aim of analysis is to describe the outcomes of learning in terms of observable learner tasks. Since we are usually quite familiar with these techniques, only a superficial description will be given here. Perhaps the most prevalent way in which this type of task analysis is performed is for an "expert", often the developer himself, to think through the sequence of tasks that the learner has to perform on the way to reaching the objective, and to list them. For many psychomotor tasks this method is quite adequate, as there

is a logical sequence of steps to work through as well as a necessary order to them. It is when this technique is applied to learning outcomes that are not performance-based that problems arise. The same result can be achieved empirically by having a subject who has already demonstrated competence with the objective go through the tasks necessary for its completion, noting everything that the subject does. This has the advantage of reducing the chances of a step being overlooked by an "expert" (which happens quite easily), but also suffers from the necessity of having to have several subjects perform the task to minimize idiosyncratic ways of doing things.

Task analysis whose purpose is to reveal the structure of a conceptual domain is possible with techniques that are presently available. There is, however, a considerable difference in the way that this type of task analysis is carried out rationally and empirically (between cells three and seven in figure 1.) The rational description of the structures of conceptual domains can be achieved by various mapping techniques. The empirical description and measuring of cognitive structures in learners can be achieved through any of several techniques for measuring the pattern and strength of the interrelationships between concepts.

Shavelson (1971) has described a set of rules and a procedure for converting prose into directed graphs. A directed graph, or Digraph, (Harary, Norman and Cartwright, 1965), in its simplest form a single line between two items linking them and also showing any implied direction in the relationship between them. For example, Shavelson's digraph of the proposition taken from a text on mechanics that force is a product of mass and acceleration is given in figure 2.

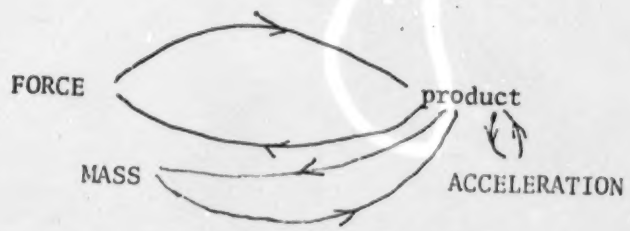


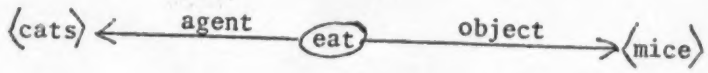
Figure 2. Digraph of the statement, "Force is the product of mass and acceleration," after Shavelson, (1971).

Here, a pattern is formed in which the concept "product" links the other three concepts together in a meaningful way. Digraphs can be constructed in this way for complex conceptual domains from the syntactical relationships that exist in prose describing them. Once a digraph has been constructed, it is a relatively simple matter to convert it into a matrix of distances between all pairs of concepts under consideration. The smallest number of lines linking "product" to each of the other three concepts in figure two is one, and the smallest number linking any two of "force", "mass" and "acceleration" is two. It is easy to see from this that "product" is closer to "force", than "mass" is, and so on. Digraph analysis therefore identifies the concepts that are present in the structure of the content to be learned, and provides an indication of the strength and direction of the relationships between them. Shavelson also describes methods for comparing digraph matrices to those derived empirically for the purpose of assessing how close learners are to having their cognitive structures correspond to the "real" structure of the content they are to learn.

There are some mathematical problems with Shavelson's method. These have been discussed adequately by Preece (1976c), and need not detain us here. However, there is one other more serious problem with Shavelson's procedure. The rules that he has developed for constructing digraphs from prose rest upon traditional rather than transformational grammar. In other words, there is a good chance that digraphs represent surface rather than deep structure. For example, "Cats eat mice" could be represented as

But this leaves out the important reciprocal relationship that mice are eaten by cats. The digraph should in fact show a symmetrical relationship between the two concepts and not a uni-directional one. One way around this problem is to construct digraphs from the apparent logical relationships between concepts rather than from the grammatical relationshps between them stated in prose. However, this too has dangers in that much more reposes upon subjective judgment rather than the application of predetermined rules.

One of the most interesting and successful attempts to map conceptual domains from the point of view of deep structure has been embodied in the research of Lindsay, Norman, Rummelhart and the group working with them known collectively as the LNR Research Group. Their theories and research have been summarized and presented in several places, (Norman, Rummelhart, et. al. 1975; Norman Gentner and Stevens, 1976). At bottom are a set of hypotheses, that through experimentation have gained the status of principles, concerning perception, memory and language. Like digraphs of conceptual domains, LNR analysis provides "maps" that identify concepts and describe the way they are interrelated and the strengths of the relationships. In addition to this, however, it also identifies the type of relationship, for example cause, location, class inclusion, and is based on deep structure rather than surface structure. "Cats eat mice" now becomes



(The actual meaning of the different symbols is given in Norman et.al. 1975, and need not concern us here). This configuration makes far more sense and gives more information than the corresponding digraph.

This method of analyzing the structure of conceptual domains has not yet been used to derive structures against which the actual cognitive structures that evolve in learners are compared. Nor has the method been used for task analysis. In some respects, it is too sophisticated for this. Maps of sentences with apparently quite simple structure appear complex and intimidating to the designer of instructional systems. However, there is no reason why the basic approach of the LNR group cannot be used in order to describe the types of relationships that exist between concepts, and to apply some of the methods suggested by Shavelson (1974) and Preece (1976b) to treat these maps in the same way as digraphs so that a numerical value can be arrived at for the distance between the concepts and thus the strength of the relationships between them. For the purposes of task analysis it is not necessary to analyze every single concept to the point of over-complexity. The subtleties of surface structure should not cloud the basic semantic network.

Methods also exist for the empirical derivation of semantic networks. The origins of the research that has given us these methods lies in the research into word association and associative meaning carried out in the fifties and sixties. (Noble, 1961: Deese, 1962, 1965) The experimental paradigm is that associations given freely to words in a meaningfully related group can, through the amount of overlap in their distributions from stimulus to stimulus, provide an indication of the amount of "common meaning" among the words in the group. Taken as a whole, often in the form of a matrix, a "map" of the meaning of the conceptual domain is offered. This matrix of "relatedness coefficients" (Garskoff and Houston, 1963) corresponds to the rationally-derived matrix of interconcept distances obtained from digraph analysis. Matrices such as this can be factor-analyzed (Deese, 1962, 1965; Winn, 1976 or scaled (Shavelson, 1972) in order to obtain a more parsimonious and more easily interpretable meaning structure. Or the interconcept distances can be converted to digraph-like tree diagrams (Waern, 1972; Preece, 1976a) for comparison with rationally-derived digraphs by inspection. As in all empirical task analysis however, it is necessary to derive structures of conceptual domains from groups rather than single subjects to avoid any misleading idiosyncracies. This can be achieved by computing relatedness coefficients between concepts from the pooled associations of all subjects (Deese, 1962), or by using an average coefficient calculated from the corresponding cells of the matrices of all subjects (Shavelson, 1972). In either case, the structural pattern that emerges will be general enough to serve as a standard towards which instruction should work. The greatest weakness that exists in this method is the assumption that free association to stimuli does in fact point to the meaning of a group of concepts. However, while on the surface it seems to be a rather haphazard way of going about the analysis of meaning, experience has shown that subjects in an experiment exhibit remarkable similarities in the patterns of their matricies, and that replications of free association studies over two or more groups of subjects likewise give highly consistent patterns. This is true even when the modality of the stimulus is varied, say from a list of words to a series of pictures (Winn, 1976). So it does appear to be a valid and useful tool for task analysis of this kind.

Moving to task analysis based upon the processes rather than the outcomes of learning, the field appears to be somewhat more barren. Resnick (1976), working particularly in the area of mathematics instruction for young children, (Resnick, Wang and Kaplan, 1973), has proposed a task analysis based upon information processing.

> Information-processing analyses are clearly distinguished from behaviorist ones by their explicit attempts to describe internal processing. They differ from the cognitivist Gestalt and Piagetian positions in their attempts to describe the actual flow of performance - to translate "restructuring" or "logical operations" into temporally organized sequences of actions (Resnick, 1976, p.64).

This description situates process-based task analysis in cell number two of figure 1. Tradionally derived, task analysis based upon information processing describes an idealized, highly efficient way of performing given tasks so that an objective can be attained. The analysis defines both concepts and processes, and the order in which they are to be dealt with.

The assumption that underlies this type of task analysis is that once the cognitive processes are known whereby the learner will acquire certain knowledge or skills, effective instruction can be designed. The advantages of beginning with processes, rather than outcomes, lie in the greater feasibility of taking differences in cognitive style and aptitude into account. Differences between learners, after all, depend almost entirely on the way in which they process and organize the information they receive and, with some obvious exceptions, only secondarily with the structures or skills that are formed as a result of the learning process. Resnick (Woods, Resnick and Groen, 1975) has shown experimentally that different children process information as they learn about mathematics in different ways. The obvious result of this is that there is likely to be a difference in the form or substance of the cognitive structures that are formed. Instruction therefore has to be designed to accomodate the information - processing tendencies of the learners which, in this case, involve differences between an incremental and decremental model of the subtraction process.

The research of the LNR group also has implications for process-based task analysis (cell one, figure 1.). Beyond the mapping techniques that the research provides,and beyond the identification of the kinds of relationships that exist between concepts within a particular semantic network, the various computer

simulations developed by these researchers using the active structural network as a model for semantic processes allow the modelling of various aspects of human information processing (Rummelhart and Norman, 1975; Rummelhart and Levin, 1975; Scragg, 1975). Scragg's development of LUIGI, a system that "knows about" cooking, is capable of answering questions put to it in English about recipes and items found in the kitchen. LUIGI demonstrates that human information processing can be modelled using semantic networks, and anticipates that we will soon be able to get a far greater understanding about the processes whereby humans interrelate concepts through use of computer modelling.

The empirical side of process-based task analysis is not easy to pin down. For structural processes, the experimental study of assimilation, accomodation and equilibrium (Piaget, 1967) is called for (cell5). For task-directed processes, the study of information processing as it relates to performance is required (cell6).

From any task analysis come enabling objectives. These identify, in objective form, the sub-steps that the learner must achieve on the way to accomplishing the main task set by the objective. Traditionally, enabling objectives are stated in behavioral terms like terminal objectives. However, task analysis aimed at determining learning processes and structural products of learning needs to come up with objectives that are a little different. An intriguing idea of "cognitive objectives" for learning has been postulated and explored by Greeno (1976). In a sense, cognitive objectives can be derived from most of the types of task analysis that we have been discussing.

> Development of instructional objectives begins with consideration of the kinds of tests used to assess whether students have acquired the knowledge intended as the outcome of learning. But rather than just specifying the behavior needed to succeed in such tasks, cognitive objectives are developed by analyzing the psychological processes and structures that are sufficient to produce the needed behaviors (p. 123)

The difference, then, between cognitive and behavioral objectives lies in the way they are derived and, consequently, what it is in learner activity that they account for. They are based on analysis of cognitive structures and processes.

From networks that owe a lot to the work of the LNR group for their construction, Greeno developes flow-charts that resemble quite closely Resnick's schematics. One way in which Greeno discusses cognitive objectives has to do with the way in which they permit learners to answer questions about the conceptual domain that is to be learned. Answering a question, of course, requires that information be retrieved from memory, and in order that learners are able to do this, instruction has to be designed in such a way that information is stored in an easily-retrievable way. The objectives therefore specify not just what is to be learned and stored in memory, but in what arrangement it is to be stored, stating which concepts are to be closely associated with which others. The semantic network provides the instructional designer with the "correct" model of the conceptual domain in memory, and this itself becomes the objective that the learner is to achieve. The learner is to structure the concepts so that they fall as closely as possible to the pattern specified by the semantic network. Learning success can then be measured by comparing the semantic network to each individual learner's cognitive structure.

Learner analysis

A knowledge of the learners who will pass through an instructional system has always been acknowledged as extremely important to the designer of instructional systems. Materials and strategies cannot be prepared unless it is known how the learner will use them and even to what extent the learner will be able to use them. Since it is generally accepted that such things as a learners age/grade, general mental ability, verbal ability, motivation and so on determine how and how much a learner can learn, these variables will not be discussed here. What is important to note, however, are those aspects of cognitive style and learner aptitude that have to do with information processing and cognitive structuring. The following discussion deals with a sample of those cognitive styles and aptitudes about which learners might be tested in order to give designers of instructional systems an idea of how and how easily cognitive structures will be formed.

Many tests of verbal reasoning tap the learner's ability to grasp the relationships between concepts. This infers a definition of verbal reasoning that stresses the ability to use language in order to integrate ideas into meaningful wholes. Clearly, this relates to deep structure and to the kinds of

structural networks that the LNR research group propose. In other words, if the learner has an aptitude for verbal reasoning, that learner should then be capable of storing and accessing concepts in memory in a way that closely parallels the model provided by the active structural network. Good verbal reasoning ability predicts logical and structured storage of concepts in memory and accurate retrieval of those concepts in a way predicted by the general network structure.

Since cognitive structures and semantic networks are meaningful in the sense that they describe which concepts are "close to" which others, scores on aptitudes to do with spatial abilities should also predict a learner's structuring ability. Abstract reasoning tests are by and large free from verbal and realistic pictorial information, and rely more on relationships between concepts expressed as diagrams, charts and so on. While the emphasis is still on the learner's ability to grasp relationships between concepts, these relationships are now supposedly independent of language. This is not to say that the learner stores concepts in the form of an "image" that looks like a diagram or chart. It is to say, rather, that skill in abstract reasoning should enable a learner to manipulate concepts, to store and to retrieve them more easily than a learner who is deficient in this ability.

Closely related to this are tests of spatial relations. Here, the analogy of a literal spatial representation of conceptual domains in memory is carried even further. The supposition is that if spatial imagery helps learners organize concepts in memory, and semantic network theory suggests that this might in fact be the case, then tests of spatial relations will allow the instructional designer get to design an instructional system that closely fits the learner's ability to structure the information it contains.

It is also reasonable to suppose that some of the various dimensions of cognitive style have to do with the ability of learners to structure information in a meaningful way. Although cognitive style is closely related to aptitude, it is perhaps useful to make a fairly subtle distinction between the two and say that cognitive style has more to do with learner preferences and tendencies than ability has. Taking field-dependence (Witkin, 1954; Witkin, Moore, Goodenough and Cox, 1977) as an example, field-dependent subjects tend to rely upon the

context of a perceived stimulus to derive its meaning, while field-independent subjects are more likely to judge stimuli independent of context. What is in question here is the way learners intuitively tend or prefer to process information rather than their actual ability to handle concepts in a particular way. Since the building of cognitive structures requires a certain amount of reorganization of ideas in memory so that the right concepts are close to each other, it is reasonable to suppose that field-independent subjects, less encumbered by the context in which the concepts were presented, would be more likely to handle this restructuring in a satisfactory manner. Similarly, on the visual-haptic dimension (Lowenfeld, 1945), it would be expected that those learners who store and process information visually would be better able to structure a conceptual domain than those who tend towards the non-visual end of the scale.

In addition to the characteristics of the learners identified by tests of aptitude and cognitive style, it is important for the instructional designer to know how much the learner knows upon entering the instructional system. Again, testing entry behavior is nothing new for instructional designers. However, when learning is defined as change in cognitive structure, entry behavior must be expressed in terms of those cognitive structures that a learner possesses relative to a particular conceptual domain before any attempt is made to change them. This assessment can be carried out in a number of ways (Scott, 1966, 1969). For example, learners can give word associations to key concepts in the conceptual domain, as was the case in empirical-structural task analysis. The matrices of relatedness coefficients for all pairs of stimuli derived from these associations then serves as a "map" of the learner's structural representation of the domain. Achievement is measured by comparing this matrix with another, derived in the same way, after instruction has taken place. Changes in structure will then become evident. Other ways of assessing the way in which learners structure conceptual domains are described by Shavelson (1974) and Preece (1976b). An intriguing alternative to free association is offered by having subjects draw tree diagrams in which lines link the related concepts and, once again, where actual physical distance measured by the number of lines, can be interpreted as the difference between concepts in memory.

In sum, learner analysis provides the instructional designer with the same kind of information that it always has. However, in addition, it must provide information about the learner's ability and tendency to structure conceptual domains efficiently and accurately, and also about the nature of cognitive structures learners possess before instruction takes place. Methods and tests for doing these things are available to the designer of instructional systems, and he should be familiar with them.

Production, testing and revision.

The final design decisions, leading to scripting of materials to be produced, and decisions concerning the instructional strategies to follow are very similar to those followed in the traditional procedures of instructional development. They will not be discussed here. However, when it comes to field-testing of the instructional system and to making revisions to it, there are differences that are peculiar to systems that take a structural approach to instruction and learning. These have primarily to do with the way in which the outcomes of learning are measured against an external criterion. Within this area, the innovations are limited to the structural aspects of learning identified in figure 1.

Techniques for the description of "ideal" structures of conceptual domains have already been described. So have methods for measuring empirically the actual cognitive structures that learners possess. It is quite simple to combine these two and compare one with the other. In this way, rationally derived "ideal" structures serve as the criteria against which learner's acquired cognitive structures can be compared. As with all field-testing, this comparison can indicate where there are mismatches between what the learner knows - the way in which conceptual domains are organized - and what he should know - the most efficient way of organizing a conceptual domain.

It is best to begin this examination of the comparison of structures with a look at the comparison of the matrices of relatedness coefficients that represent them. This is the technique used with mixed success by Shavelson (1972) and by Preece (1976a). Shavelson calculated the euclidean distances between matrices of relatedness coefficients for groups of subjects and one derived from digraph analysis. In this method, the differences between the coefficients in each pair of corresponding cells are squared, added together,

and the square root of this sum is taken. This is an adequate measure of the distance between the two matrices. There is one serious problem, though. As Preece has demonstrated (1976c), the distance between the two matrices depends as much on the absolute values of the cells as it does on the differences between them. Euclidean distance is therefore not independent of the mean amount of overlap, and as a result, unless the relatedness coefficients of the two matrices are just about the same absolute value, euclidean distance is meaningless. After all, developmental testing should identify discrepancies in pattern, not just amount, of the two structures. One way to overcome this problem would be to express both the relatedness coefficients of the learners and of the criterion matrix as standard scores, after calculating the mean coefficient for each. The absolute value of the scores would therefore no longer be relevant.

A second way of measuring the correspondence of a subject's matrix with a criterion matrix is suggested by Preece (1976c), who recommends Johnson's (1967) method of rank-order correlation between two matrices as appropriate for comparing matrices. Like euclidean distances, rank-order correlation coefficients (Spearman's rho) are computed from the squared distances between pairs of corresponding cells. However, this time the cells have integer values that express the rank order of their size, not their absolute value. Thus, by ranking cells in order of size before calculating the distances between them, the problem of absolute values encountered by Shavelson is avoided. The values of rho indicates the proximity of subjects' matrices to the criterion matrix, and can be used as scores in common statistical procedures to test for differences between pre- and post-test means, and to indicate how much change of cognitive structure has actually taken place, as well as to show the places where the structure of parts of the conceptual domain is still some distance from the criterion. (The statistical significance of rho is not relevant in this procedure, although a significant rank-order correlation between a relatedness coefficient matrix for a group of learners and a criterion matrix indicates a reasonably close fit between what has been learned and the criterion.)

Aside from the euclidean distance computed from standard scores and the rank-order correlation coefficient, there are other statistics about relatedness coefficient matrices that are useful in the testing and revision of instructional systems. One of these is an average (mean or median) coefficient for each subject or group. This figure indicates the mean amount of overlap

between the distributions of words given as associates to all possible pairs of stimuli. It can be interpreted as giving an indication of the "structuredness" of a particular conceptual domain realized by a subject or group. The average for a rationally derived matrix indicates the "structuredness" of the content that is to be learned. A low value indicates a relatively low amount of structure because few associations are common to more than one stimulus concept. A high value indicates a greater amount of structure, since many of the associations are give to two or more stimuli.

The mean number of actual words given as associations to stimuli by a learner is also useful to know. This statistic can be interpreted to indicate the "meaningfulness" of the conceptual domain to the learner (Noble, 1961). The more associations that are given, the more meaningful the domain is. Although an increase in meaningfulness is often accompanied by an increase in structuredness, as seems reasonable, mathematically the number of associations given is independent from the amount of overlap and themean relatedness coefficient. For example, a conceptual domain can be meaningful for a learner. But unless the concepts within it are perceived to be highly interrelated as well as being meaningful in themselves, the apparent structuredness will be low. Similarly, a meaningful conceptual domain can be at a great "distance" from the criterion if the learner has organized it in a highly idiosyncratic fashion. Or a highly structured set of concepts can also be a long way from the criterion for similar reasons.

For the instructional designer, then, euclidean distance and/or rho, the mean relatedness coefficient and the mean number of association given to the stimulus concepts can tell a lot about how the instructional content has been structured by individual learners and by groups. In an effective instructional system, it would be expected that the matrices obtained empirically from the testing of learners, indicating their cognitive structures, would become closer to a criterion matrix, describing an "ideal" structure, would become more structured and also more meaningful. In other words, euclidean distances would decrease, or values of rho increase, mean relatedness coefficients would increase, and so would the mean number of associations given to stimuli. Just how much change would be necessary to satisfy the designer would be decided in the usual ways. A general lack of increase in any of these variables would indicate quite simply that the system was not working well.

However, using the three structural measures just described, further diagnosis of problems in the system would be possible. An increase in meaningfulness without an increase in the proximity of learners' cognitive structures to the criterion would suggest that the instruction was successful in teaching what the individual concepts were, but was not succeeding in getting across the way in which they were related. An increase in structuredness but not in the proximity of the structure of what the learners were learning to content structure would suggest that the instruction was teaching the wrong structural arrangement of the conceptual domain. An increase in the proximity of learner's cognitive structures to the criterion but not in meaningfulness would indicate learners were trying to organize ideas that they did not really understand and were successful, perhaps, because they could memorize what they had to learn. These, and all other permutations of increase or stability in the three variables, would permit the instructional designer to modify the system in any of a number of ways.

Once satisfied with the performance of the system after several rounds of such testing and revision, the designer would be ready to implement the system in the educational setting for which it was designed. In this, there would be no real difference from the way things are done at present.

To summarize, here are the steps the instructional designer will follow in order to create an efficient and effective instructional system based upon cognitive psychological principles, a structural approach to learning and instruction, and measures of cognitive structure and structural change in learners to describe the outcomes of learning.

1. Define the goal of the system.
2. Perform a task-analysis. Analyze motor skills and clearly behavioral tasks in the traditional way. Analyze any intellectual tasks in terms of the cognitive structures that they are intended to produce. Either describe the structure of the content to be learned rationally through digraph analysis or by preparing semantic networks. Or achieve the same ends empirically by analysis of matrices derived from conceptual domains as structured by experts. Attention should also be paid as much to the cognitive processes the learner will have to go through as the structures that the processes create.

3. State cognitive objectives.
4. Perform a learner analysis. Identify aptitudes and cognitive styles that are pertinent to the way in which the learners are likely to structure the information they are to learn. From association tests, or tree construction, find out the state of the cognitive structures of the learners before instruction so that instruction can be shaped to capitalize on what exists in memory and also to supply what is missing.
5. Design and produce a prototype of the system.
6. Try the system out. Using measures of intermatrix distances, structuredness and meaningfulness, assess both changes from pretest scores and discrepancies from the criterion.
7. Revise as necessary.
8. Implement the system.

As educators become more concerned with the structure of knowledge and with the ways in which learners process information, it is becoming more and more important to develop instructional systems that take into consideration cognitive structure and the ways in which these structures are formed and changed. Instructional development has been traditionally very much bound by an analysis of observable learner behavior, and has thereby imposed upon itself limitations that have been detrimental to the effectiveness of instructional materials and strategies in the classroom. This has been emphasized by our increasing knowledge of how individual differences between learners affect learning and the management of learning, and our awareness of the fact that individual learners are complex creatures who bring to the classroom far more than a given knowledge of a subject and a repertoire of observable behaviors. The above, sketchy though it be, is an attempt to map out a set of procedures for the designer of instructional systems that reconciles our changing awareness of the learner and learning with the need to develop effective instruction that can cater to learners of all kinds in an institutional setting. Clearly, a vast amount of work remains to be done both in the area of research on learning and in ways to make it operational in the classroom. Let us hope that this work will be quickly taken up by researchers and developers.

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